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TECH. NOTE STRUCTURES 336

ROYAL AIRCRAFT ESTABLISHMENT

(FARNBOROUGH)

TECHNICAL NOTE No. STRUCTURES 336

AN ANALYSIS OF FATIGUE LOAD METER RECORDS FOR LIGHTNING FAW Mks.1 AND 1A AIRCRAFT IN R.A.F. SQUADRON USE [U]

by

F. W. Johnson, I.S.O., B.Sc.(Eng.) and Vera J. Pike, B.Sc.

JUNE, 1963

MINISTRY OF AVIATION

U.D.C. No. 533.6.048.1 : 620.178.3 [AI] (42) Lightning FA7 Mk.1

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RAE Ref: Structures/E/16524

SUMMARY

Fatigue load meter records covering 4315 hours flying by 37 Lightning FAW Mks.1 or 1A aircraft in R.A.F. Squadron use up to February, 1962 have been analysed and load spectra have been drawn for six different types of flying and for all the flying combined. Comparison is made with the load spectrum from which the loading applied in a fatigue test on the wing was derived.

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1 INTRODUCTION

Fatigue load meter records for Lightning FAW Mks.1 and 1A aircraft in R.A.F. Squadron use were examined to ascertain the frequencies of acceleration occurring in various types of flying and to enable an overall comparison to be made with the loading data adopted in 1959 for fatigue tests of the wing structure.

The records available, which were lent to the R.A.E. by the Air Ministry, covered the aircraft of three squadrons up to February, 1962. Recording began in No. 56 Squadron in January, 1961, in No. 74 Squadron in August, 1960 and in No. 111 Squadron in April, 1961. Thirty-seven aircraft were involved and the usable records covered a total of 4315 hours flying.

With very few exceptions the fatigue meter had been read after each flight and, by analysis of the records, it was possible to obtain a load spectrum for each type of flying in addition to an overall average load spectrum. Two types of fatigue meter were used, the Type 2D with six acceleration levels and the Type 14 with eight. It was assumed that the Lightning Mks.1 and 1A had the same flying characteristics and, therefore, that the results from each could be combined in the analysis.

2 ANALYSIS OF RECORDS

The fatigue meter records give the duration of each flight, the type of flying or duty carried out, the fatigue meter readings and certain other information not of interest for the present Note. Examination of the records showed that the flying could be divided into the following categories and the records were analysed to obtain the hours flown and the fatigue meter counts at the various 'g' levels in each category.

	Category	Remarks
1	P.I's	Practice interceptions, including scramble and cine camera exercises.
2	Radex	Radar exercises. It was subsequently ascertained that this type of sortie could be taken as being the same as a practice interception.
3	Navex	Navigation exercises with which have been included transit, ferry, practice diversion, reconnaissance and cross country flights.
4	Instrument approach	This includes GCA, ILS, TACAN, practice PAN (short for "panic") and let-downs.
5	Local	Local flying, not more explicitly defined; the amount is very small.
6	Target	One aircraft acting throughout the flight as a target for others.

	Category	Remarks
7	Initial familiarisation	This covers a limited amount of flying by the first squadron to receive the Lightning.
8	Air test	A flight test by the R.A.F. after maintenance or modification of the aircraft. Pre-delivery flight testing is not included since the records were not immediately available.
9	Convex	Conversion exercises and familiarisation other than that included in Category 7.
10	Handling	General flying on no particular defined duty.
11	Formation	All formation flying, including fly-pasts and displays.
12	Aeros.	Aerobatics and individual demonstrations.
13	Chase and gunfiring	Very small amounts of somewhat similar flying in each of these duties have been combined.

The amount of flying in each category in hours and as a percentage of the whole is shown in Table 1 for each squadron and for all three squadrons combined. The total counts for each type of fatigue meter in each category of flying are given in Table 2; these totals were obtained by adding the counts for all the aircraft in the three squadrons for the appropriate meter and category of flying. Rather more than half the total flying was recorded by the Type 2D meter. This flying occurred early in the period under review since the Type 2D meter was fitted first and was replaced by the Type 14 meter when supplies of the latter became available.

The basis chosen for comparing various types of flying was the fatigue damage rate for the most critical part of the wing structure as determined in the fatigue test. The damage rate would normally have been obtained from calculations based on the load spectrum and on stress-endurance information for the appropriate flight conditions but it was considered that, for the comparison required, sufficient accuracy would be obtained by use of the fatigue meter formulae. These formulae are provided by the aircraft manufacturer to enable the Service to ascertain from the meter readings the percentage of wing fatigue life used. Separate formulae are given for each type of meter and for different aircraft flying weights. These formulae, therefore, give a measure of the fatigue damage done and can be used to show the relative damage caused by the different types of flying.

For this analysis the formulae appropriate to a mean aircraft weight of 31,000 lb have been used for both Type 2D and Type 14 meters, (see Appendix 1). The relative damage rates obtained from these formulae are given in columns 2 and 3 in Table 3 for each type of flying. The two values were then combined in proportion to the amount of flying covered by each type of meter and the overall values are given in column 4. These values show broad similarities

of damage for some categories of flying and in order to simplify the analysis these have been combined in columns 5, 6 and 7 to give damage rates for six main groups of flying duties. Lastly in column 8 the overall relative damage rates have been reduced to equivalent damage rates by assuming a damage rate of unity for the group with the greatest number of flying hours. The percentage of flying time in each group is given in column 9.

3 LOAD SPECTRA

For the six groups of flying referred to above, the acceleration frequencies in counts per hour were calculated from the data in Table 2. These frequencies are given in Table 4 and are shown plotted in Figs.1 to 3 which give curves representing the combined results derived from the two types of fatigue meter. It will be noted that four g levels are common to both meters and for these the combined frequencies can be calculated; for other g levels the approximate combined frequencies were estimated and the values given in brackets in Table 4 were read from the resulting curves. The mean frequencies for all the flying combined, which are given at the bottom of Table 4 and shown plotted in Fig.4, were obtained by combining the mean frequencies for each group in proportion to the amount of flying done.

It should be noted that the load spectra for aerobatics and for chase and gunfiring (Fig.3) are based on relatively small amounts of flying and might possibly be altered when more records are available.

4 DISCUSSION OF RESULTS

The various groups of flying can be compared directly by means of the equivalent damage factors given in column (8) of Table 3, the factor for all the flying combined being 2.51. These factors show that some types of flying can be very severe from fatigue aspects; for example, one hour's flying on individual aerobatics gives the same expenditure of fatigue life as 29.3 hours flying on practice interceptions or similar duties. Formation flying has a particularly important influence on life usage because not only is the equivalent damage factor large (9.8) but the amount of flying is also large (nearly 12% of all flying).

From Fig.3 it will be observed that in both aerobatics and formation flying the frequency of counts at the 1.75 g level was less than expected from extrapolation of the upper curve of the load spectra. This probably arises from a design characteristic of the Type 14 meter[1] which does not record a count of 1.75 g until the acceleration, having reached or exceeded that value, is reduced slightly below 1 g. Thus under sustained acceleration such as in aerobatics or formation flying the 1.75 g level could be missed while higher levels which do not require a return to below 1 g are counted. This is shown on some records where the number of counts at 2.5 g is greater than those at 1.75 g. In a few isolated flights the number of 3.5 g counts exceeded the number of 2.5 g counts. From damage estimates using the fatigue meter formula, it was concluded that under-counting at the 1.75 g or 2.5 g levels to the extent so far observed has a very small effect on fatigue life and no adjustment of the formulae is necessary on this account.

From Fig.4, in which the average fatigue meter load spectrum is compared with the wing test spectrum, it will be noted that high accelerations (i.e. 4 g and above) were applied less frequently and positive accelerations up to 3 g more frequently than allowed for in the test spectrum. Moreover, downward accelerations below 1 g occurred much more frequently than expected and this is undoubtedly due to the relatively large amount of formation and other low altitude flying recorded. At the time of the wing test, there was insufficient information available from Lightning fatigue meter records and the test loading, therefore, was based on Hunter and Javelin fatigue meter records, on Meteor V-g records and on standard gust data related to the Lightning interceptor sortie pattern. Despite this, the damage rate for all the service flying combined was only about 8% more than the damage rate estimated for the wing test load spectrum using the fatigue meter formula.

5 SUMMARY OF RESULTS AND CONCLUSIONS

(i) Load spectra have been obtained for various types of flying and these have been compared on the basis of fatigue damage as estimated by the fatigue meter formulae issued for monitoring wing life usage. Some types of flying, notably individual aerobatics and formation flying, can be very damaging compared with practice interceptions and similar duties. Formation flying has an important influence on fatigue life usage since this constituted nearly 12% of all flying in the period reviewed.

(ii) When the average load spectrum obtained from all the fatigue meter records was compared with the wing test spectrum, service flying was found to be 8% more damaging than the flying represented in the test. The difference is remarkably small having regard to the sources of information for the test load spectrum and the variety of flying carried out by Lightning aircraft.

LIST OF REFERENCES

Ref. No.	Author	Title, etc.
1	-	General Instruments - Accelerometers and fatigue meters. Air Publication 1275A, Volume 1, Section 12.

ATTACHED:-

Appendix 1 — Figures 1 - 4 SME.88203/R - 88206/R
Tables 1 - 4 — Detachable abstract cards

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APPENDIX 1

LIGHTNING FAW 1 AND 1A
FATIGUE METER FORMULAE FOR DETERMINING THE PERCENTAGE OF WING LIFE USED

Type 2D meter (Mean aircraft weight = 31,000 lb)

$$\% \text{ life used} = \frac{1}{1000}(1.7h + 7.25A + 8.15B + 2.05C + 7.6D + 16E + 20F)$$

where h = number of hours flying in the period considered and A, B, C ... are the counts at acceleration levels of -1.5, -0.5, 2.5, 3.5, 4.5 and 6.0g respectively.

Type 14 meter (Mean aircraft weight = 31,000 lb)

$$\% \text{ life used} = \frac{1}{1000}(7.25A + 6.3B + 1.8C + 0.109D + 2E + 10F + 17G)$$

where A, B, C ... are the counts at acceleration levels of -1.5, -0.5, 0.25, 1.75, 2.5, 3.5 and 5.0 g respectively. Any counts at the 7.0 g level are ignored.

TABLE 1

Lightning F/W 1 and 1A

Amount of flying in each category

Category of flying	No. 56 Sqdn.		No. 74 Sqdn.		No. 111 Sqdn.		Total hours	% of grand total hours
	Hours	%	Hours	%	Hours	%		
1 P.Is.	82:55	6.7	793:05	46.3	109:20	8.0	985:20	22.85
2 Radex	726:45	59.0	0:45	0.05	779:40	56.9	1507:10	34.95
3 Navex	96:10	7.8	61:10	3.55	73:30	5.35	230:50	5.35
4 Instrument approach	12:05	1.0	66:00	3.85	70:05	5.1	148:10	3.45
5 Local	29:15	2.4	:50	0.05	11:50	0.85	41:55	0.95
6 Target	115:00	9.35	40:10	2.35	79:05	5.8	234:15	5.4
7 Initial familiarisation	-	-	97:15	5.7	-	-	97:15	2.25
8 Air test	32:25	2.65	18:35	1.1	24:20	1.75	75:20	1.75
9 Convex	75:45	6.15	90:10	5.25	112:20	8.2	278:15	6.45
10 Handling	9:45	0.8	96:40	5.65	15:30	1.1	121:55	2.8
11 Formation	31:30	2.55	405:15	23.65	74:35	5.45	511:20	11.85
12 Aeros	17:20	1.4	29:00	1.7	7:25	0.55	53:45	1.25
13 Chase and gunfiring	2:50	0.2	13:30	0.8	13:05	0.95	29:25	0.7
Total hours	1231:45	-	1712:25	-	1370:45	-	4314:55	-

TABLE 2

Lightning F/W 1 and 1A

Acceleration counts recorded in various categories of flying

Category of flying	Counts at various acceleration levels and corresponding period of flying														
	Type 2D fatigue meter							Type 14 fatigue meter							
	g levels reached or exceeded						Period in hours	g levels reached or exceeded							Period in hours
	-1.5	-0.5	2.5	3.5	4.5	6.0		-1.5	-0.5	0.25	1.75	2.5	3.5	5.0	7.0	
1 P.1s	1	23	1521	260	39	2	545:30	0	21	147	3383	977	206	8	0	339:50
2 Radex	0	11	1301	229	34	1	542:40	1	9	326	9240	2306	370	16	1	964:30
3 Havex	0	7	260	63	15	0	100:00	0	15	64	771	261	57	2	0	130:50
4 Instrument approach	3	16	176	32	1	0	83:00	0	7	31	434	136	23	1	0	65:10
5 Local	0	0	73	14	3	0	26:20	0	0	6	162	38	6	0	0	15:35
6 Target	0	1	199	55	9	0	105:55	0	2	44	762	287	49	0	0	128:20
7 Initial familiarisation	0	9	779	133	14	0	97:15	-	-	-	-	-	-	-	-	-
8 Air test	2	30	147	36	5	1	35:05	2	10	56	518	216	59	3	0	40:15
9 Convex	0	16	774	136	8	0	233:45	0	3	41	514	210	30	2	0	44:30
10 Handling	0	10	243	53	9	0	86:05	1	3	22	353	121	34	5	0	35:50
11 Formation	18	148	11821	1363	242	8	343:20	0	8	492	5750	4242	572	29	0	168:00
12 Aeros	21	73	1719	493	211	26	33:00	8	47	127	797	693	277	55	0	20:45
13 Chase and gunfiring	0	0	59	5	1	0	17:15	0	0	3	210	84	34	2	0	12:10
Totals	45	344	19102	2872	591	38	2349:10	12	125	1359	22894	9571	1717	123	1	1965:45

TABLE 3

Lightning FAW 1 and 1A

Relative damage rates and equivalent damage factors for various types of flying

Category of flying	Relative damage rates			Relative damage rates with certain categories combined			Equivalent damage factors with major role taken as unity	Total flying in group as % of total flying in all groups
	Type 2D meter	Type 14 meter	2D and 14 meter results combined	Type 2D meter	Type 14 meter	2D and 14 meter results combined		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 P.Is	1.09	1.45	1.21					
2 Radex	1.10	1.06	1.08					
3 Navex	1.43	1.09	1.26					
4 Instrument approach	1.10	1.02	1.07	1.13	1.13	1.13	1.0	72.95
5 Local	1.32	1.05	1.22					
6 Target	1.09	0.96	1.02					
7 Initial familiarisation	3.16	-	3.16	3.07	3.25	3.11	2.75	4.0
8 Air test	2.83	3.25	3.05					
9 Convex	1.40	2.03	1.50	1.42	2.08	1.55	1.37	9.25
10 Handling	1.48	2.15	1.68					
11 Formation	11.8	9.68	11.1	11.8	9.68	11.1	9.8	11.85
12 Aeros	36.5	27.8	33.1	36.5	27.8	33.1	29.3	1.25
13 Chase and gunfiring	1.18	4.69	2.63	1.18	4.69	2.63	2.33	0.7

Note:- By adding the products of the last two columns and dividing by 100 a value of 2.51 is obtained for the equivalent damage factor for all the roles combined in the proportions given.

TABLE 4

Lightning FAW 1 and 1A

Acceleration frequencies for various types of flying

Type of flying		Counts per hour at the following g levels										Hours covered by records
		-1.5	-0.5	0.25	1.75	2.5	3.5	4.5	5.0	6.0	7.0	
Practice interceptions, etc.	(a)	0.0027	0.039	-	-	2.35	0.434	0.067	-	0.002	-	1503:25
	(b)	0.00061	0.033	0.376	8.97	2.44	0.432	-	0.016	-	0.00061	1644:15
	(c)	0.0016	0.036	(0.375)	(8.97)	2.39	0.433	(0.067)	(0.023)	(0.002)	-	3147:40
Initial familiarisation and air tests	(a)	0.015	0.295	-	-	7.00	1.28	0.144	-	0.0075	-	132:20
	(b)	0.050	0.240	1.39	12.9	5.37	1.47	-	0.075	-	0	40:15
	(c)	0.023	0.284	(2.77)	(20)	6.62	1.32	(0.20)	(0.075)	(0.0060)	-	172:35
Conversion exercises and handling	(a)	0	0.081	-	-	3.18	0.591	0.053	-	0	-	319:50
	(b)	0.012	0.075	0.784	10.8	4.12	0.797	-	0.087	-	0	80:20
	(c)	0.0025	0.030	(0.8)	(10.8)	3.37	0.632	(0.08)	(0.025)	-	-	400:10
Formation	(a)	0.052	0.431	-	-	34.4	3.97	0.705	-	0.023	-	343:20
	(b)	0	0.048	2.93	34.2	25.2	3.40	-	0.173	-	0	168:00
	(c)	0.035	0.305	(3)	?	31.4	3.78	(0.62)	(0.225)	(0.022)	-	511:20
Aeros	(a)	0.636	2.21	-	-	53.0	14.9	6.39	-	0.788	-	33.00
	(b)	0.386	2.27	6.12	38.4	33.4	13.3	-	2.65	-	0	20:45
	(c)	0.540	2.23	(7.0)	?	45.4	14.3	(5.6)	(3.1)	(0.71)	-	53:45
Chase and gunfiring	(a)	0	0	-	-	3.42	0.290	0.058	-	0	-	17:15
	(b)	0	0	0.247	17.3	6.90	2.79	-	0.164	-	0	12:10
	(c)	0	0	(0.257)	(17.3)	4.86	1.33	(0.25)	(0.08)	-	-	29:25
Mean of all types of flying		0.0132	0.109	(0.9)	?	6.64	1.06	(0.21)	(0.088)	(0.013)	?	4314:55

Note:- The values obtained from the Type 20 and 14 fatigue meter records are given at (a) and (b) respectively and the combined values are given at (c). The values in brackets were read from the curves in Figs 1 to 4.

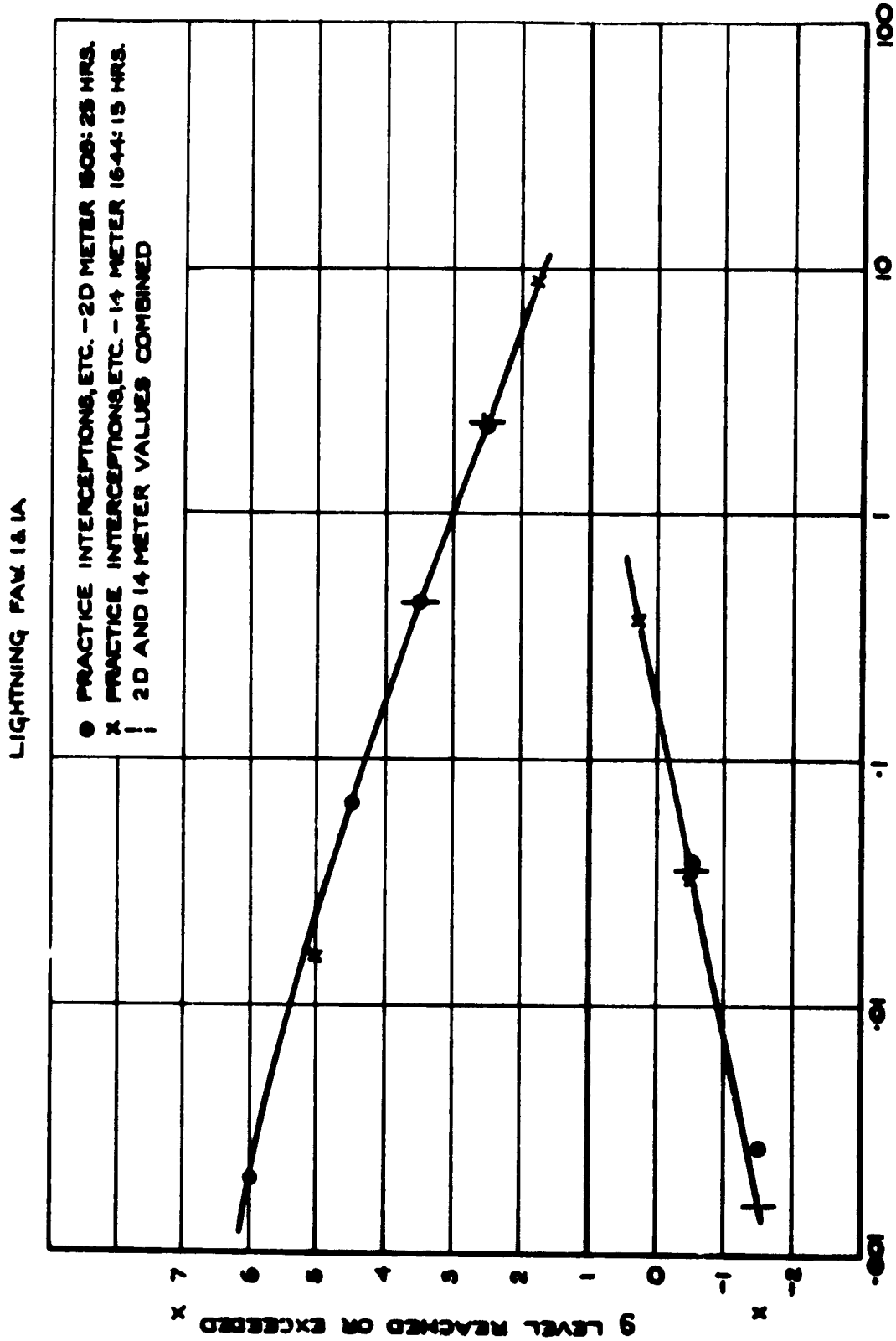

FIG. I. LOAD SPECTRUM FOR PRACTICE INTERCEPTIONS & SIMILAR DUTIES.

FIG.2.

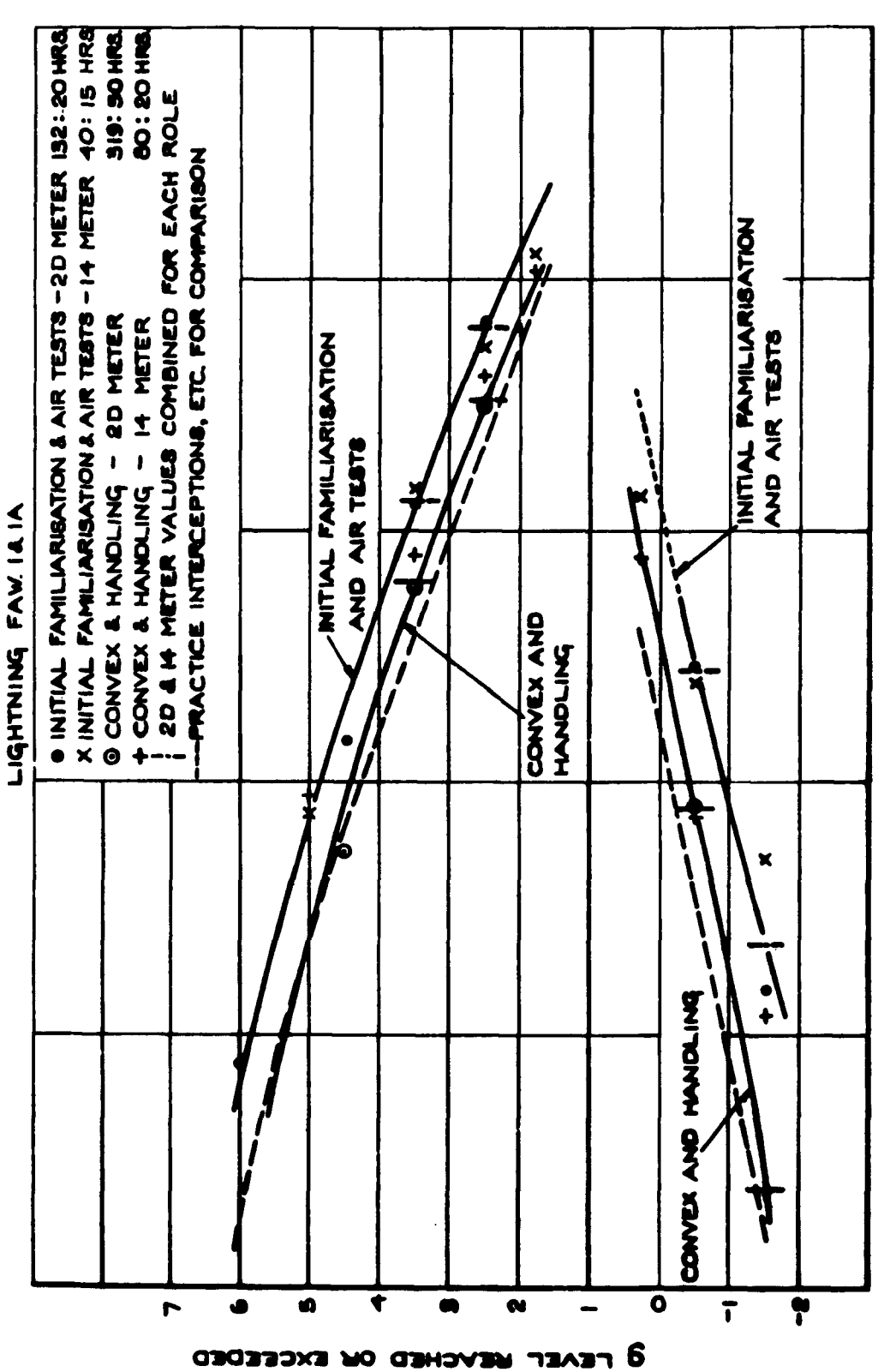

FIG. 2. LOAD SPECTRA FOR (a) INITIAL FAMILIARISATION AND AIR TESTS AND (b) CONVERSION EXERCISE AND HANDLING.

FIG. 3.

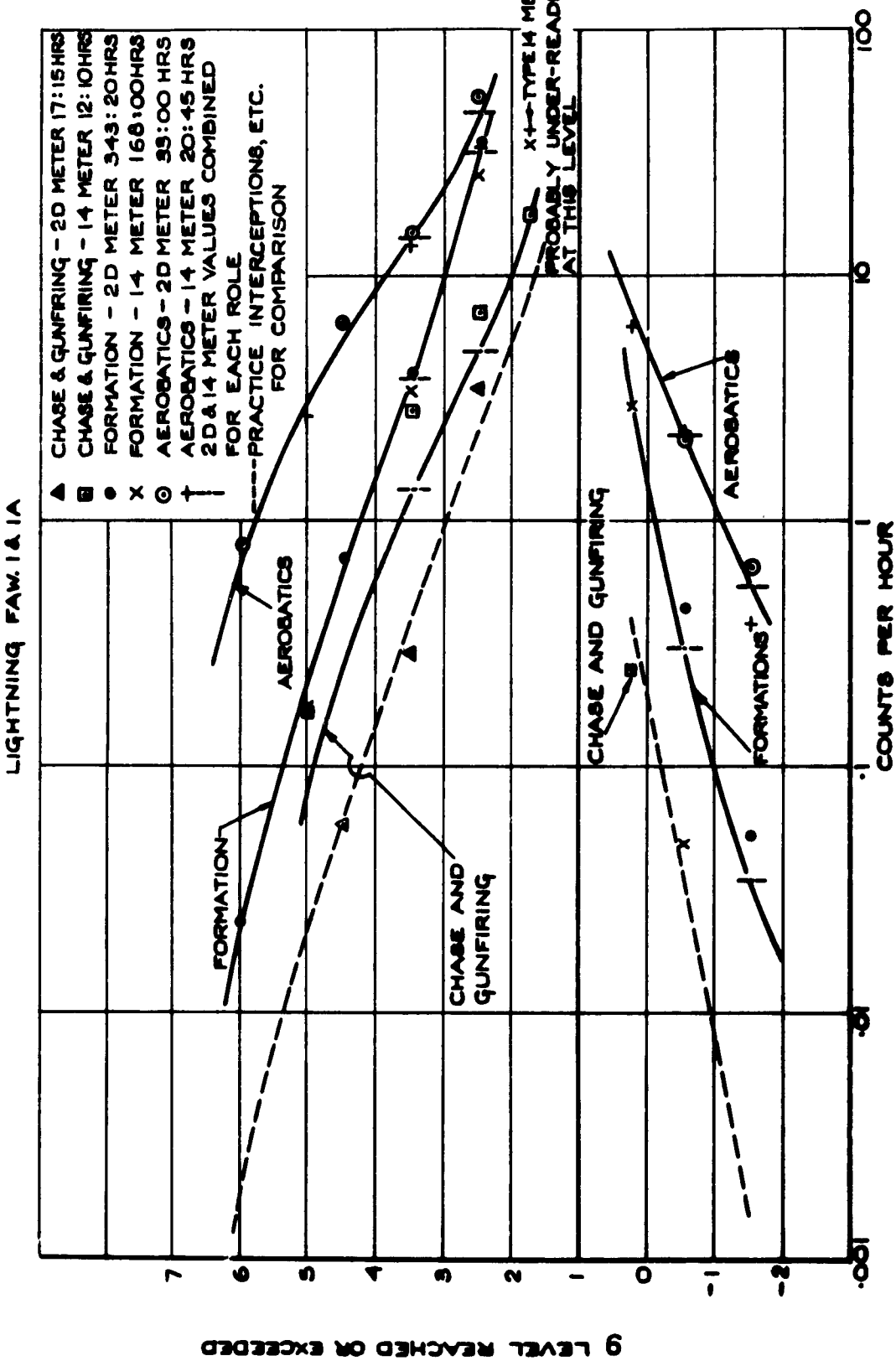

FIG. 3. LOAD SPECTRA FOR (a) FORMATION FLYING (b) AEROBATICS AND (c) CHASE AND GUNFIRING

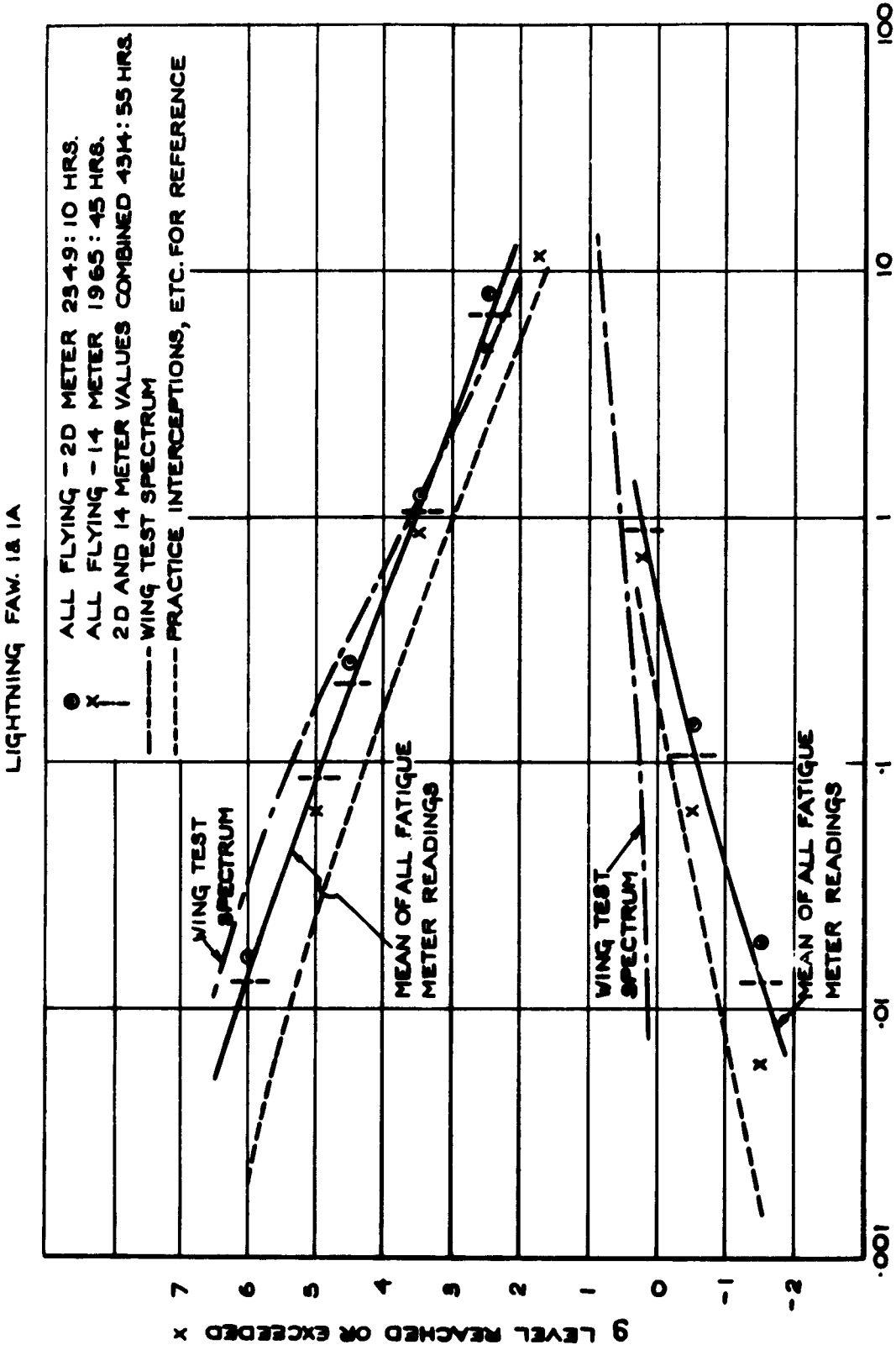

FIG.4.

FIG4. COMPARISON BETWEEN WING TEST SPECTRUM AND AVERAGE LOAD SPECTRUM FROM FATIGUE METER RECORDS.

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